Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada

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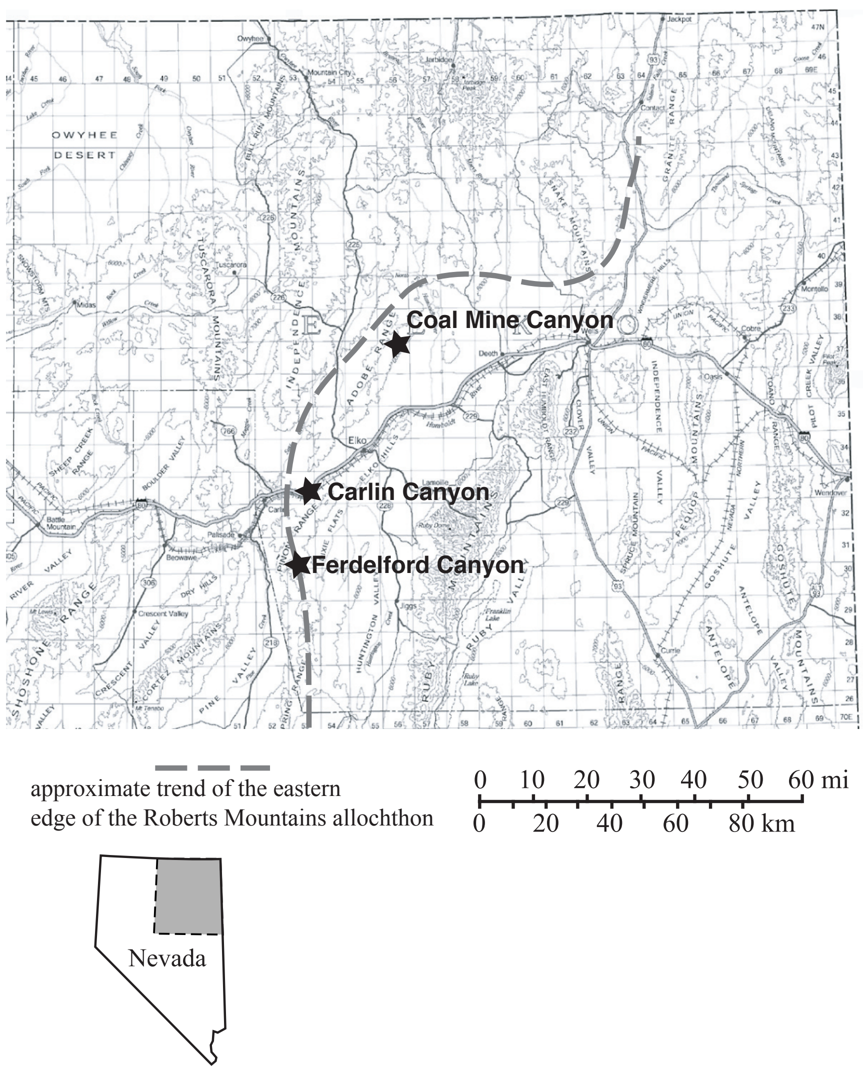

Figure 1. Map of northern Nevada showing the location of areas described in the road log.

The Western Margin of North America After the Antler Orogeny: Mississippian Through Late Permian History in the Basin and Range, Nevada

By James H. Trexler, Jr.[1], Patricia H. Cashman[1], Walter S. Snyder[2], and Vladimir I. Davydov[2]

Overview

This field trip will examine the evidence for Mississippian, Pennsylvanian and Permian deformation events in north-central Nevada. These events are notable for their timing—*after* the Antler orogeny and well *before* the Sonoma orogeny (both as traditionally defined)—and, locally, for their intensity. On this trip, we will demonstrate that these deformation events are linked to unconformities that separate genetically related stratigraphic packages in the upper Paleozoic section. These unconformities can be recognized over wide areas, can be correlated at a regional scale, are synchronous (within the resolution of biostratigraphy), and are accompanied by marked facies changes. In each case, the subunconformity rocks or their correlatives have a deformation history not recorded in the overlying rocks. These unconformities are, therefore, important stratigraphic markers with tectonic significance. We refer to these as tectonostratigraphic boundaries.

On the first day, we will drive from Boise to Elko, with a possible Stop along Nevada State Highway 225 in the northern Adobe Range (approximately 4 mi west of Elko) to see Mississippian rocks of the Antler foreland and Permian overlap strata. On the second day, we will see mid-Mississippian deformation at Ferdelford Canyon in the Piñon Range, and mid-Mississippian, mid-Pennsylvanian and early Permian deformations at Carlin Canyon in the southern Adobe Range. Here, the deformations have distinctive fold styles and geometries, as well as different ages. On the third day, we will drive through a thick succession of Early Mississippian foreland basin strata structurally overlain by Roberts Mountains allochthon, all depositionally overlapped by Middle (?) Permian strata.

Our interpretations are the product of a truly multidisciplinary study and would not have been possible without the full participation of sedimentologists, biostratigraphers, and structural geologists. Complete documentation of the map relationships, age control, stratigraphic revisions, and structural analyses in this study is beyond the scope of this guidebook paper, but is presented in two recent publications: Trexler and others (2003) and Trexler and others (2004). Reprints of these papers will be provided to field-trip participants.

Background

The conventional tectonic interpretation of the evolution of western North America is that there were two major orogenies in Paleozoic time; however, this does not explain the numerous local and regional-scale tectonic events recorded in Late Paleozoic rocks. The Late Devonian Antler orogeny and the Permo-Triassic Sonoma orogeny are both characterized as the eastward emplacement of oceanic facies sedimentary and volcanic rocks over continental margin sedimentary rocks (Roberts, 1951; Roberts and others, 1958; Silberling and Roberts, 1962). Many syntheses (*e.g.*, Burchfiel and Davis, 1972, 1975; Speed and Sleep, 1982) propose that a long-lived subduction zone oriented down-to-the-northwest, possibly accompanied by slab roll-back to the east (*e.g.*, Dickinson, 2000), was responsible for the east-directed Antler and Sonoma orogenies and all activity in between. This model is not robust in predicting the angular unconformities, disconformities, and deformation documented by many workers in upper Paleozoic rocks (*e.g.*, Dott, 1955; Johnson and Visconti, 1992; Schwarz and others, 1994; Snyder and others, 1997; Silberling and others, 1997; Ketner, 1998; Schiappa and others, 1999; Trexler and Giles, 2000). In this study, our objective has been to constrain tectonic models by determining the timing, extent, and kinematics of these short-lived upper Paleozoic tectonic events.

Our work throughout Nevada has shown that there are a number of regional unconformities from middle Mississippian through Permian time, and that they all represent genetically important breaks in the stratigraphic record (fig. 2) (Snyder, 2000; Trexler and others, 2003, 2004). These unconformities are tectonically generated and are nearly isochronous (to the resolution of Upper Paleozoic biostratigraphic control, ±~1 to 5 m.y.). More importantly, these unconformities can be correlated laterally to "event horizons" (*e.g.*, lithofacies shifts) that have the same origin. This feature makes them useful far beyond the areas of actual uplift, deformation, and erosion.

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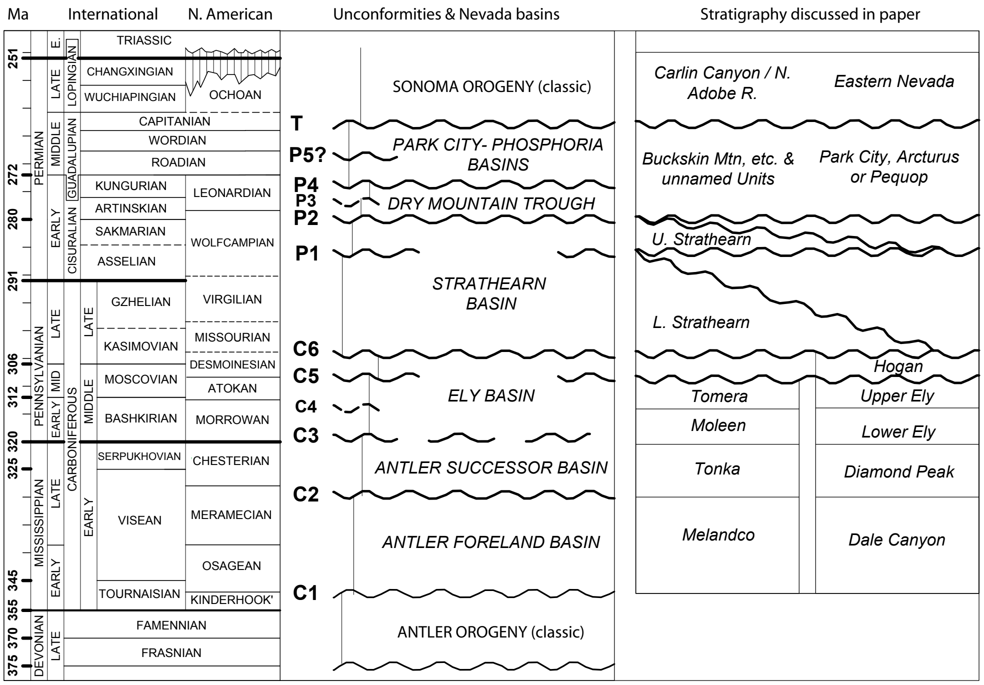

Figure 2. Regional stratigraphy of northern Nevada, showing the major tectonostratigraphic boundaries discussed in the text.

We have adopted a numbering scheme for the regional unconformities, using a system much like that used for the Mesozoic section on the Colorado plateau (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979). They are numbered sequentially from oldest to youngest within each time period (fig. 2). For the upper Paleozoic, we use the time periods C = Carboniferous, P = Permian (Snyder, 2000; Trexler and others, 2003, 2004). Our reassessment of the late Paleozoic stratigraphy in Nevada uses these unconformities and their correlative event horizons as natural breaks that separate packages of genetically related strata.

We have revised the regional stratigraphy based on our recognition of widespread unconformities in the Upper Paleozoic record. In many cases, these unconformities occur within existing mapped formations (Trexler and others, 2003, 2004). Each unconformity is, by definition, a boundary of at least formation rank; it, therefore, requires stratigraphic revision where it breaks an existing formation. Some of the unconformities can be mapped laterally into areas where the underlying rocks are deformed; these we have identified as key stratigraphic markers with tectonic significance. Some unconformities can also be traced laterally into areas where they are conformable surfaces with minor or no hiatus. Even in these cases, a signal may exist in the form of a facies change forced by the same tectonic disruption. Correlation of the unconformities with their correlative conformable surfaces is made possible by detailed biostratigraphy.

This unconformity-based analysis documents several widespread deformation and uplift events in the upper Paleozoic *between* the Antler and Sonoma orogenies. There are three of primary importance:

(1) The Mississippian C2 unconformity records Meramecian deformation of Antler foreland basin deposits, overlapped by Chesterian strata. It is particularly well developed in the Piñon Range.
(2) The Pennsylvanian C6 unconformity (recognized by Dott, 1955) truncates thrust-related deformation in rocks as young as Atokan and is overlain by middle Missourian strata.
(3) The early Permian P1 unconformity post-dates folding in the Virgilian (and older) section and is covered by Wolfcampian (upper Asselian-lower Sakmarian) sedimentary rocks. The latter two deformation events are visible at Carlin Canyon.

Recognition and widespread correlation of tectonic boundaries would not be possible without biostratigraphic age control. We are fortunate in this part of the section to have high-resolution biostratigraphy provided by small foraminifera and fusulinids. These fossils provide age resolution on the order of ±1 m.y.

Part 1: Deformation of the Antler foreland in the northern Piñon Range

Unconformity-bounded stratigraphic packages in the Mississippian and Pennsylvanian–A quick summary

Mississippian and Pennsylvanian-Early Permian strata in the Carlin area are characterized by genetic stratigraphic packages that were deposited in response to tectonic deformation, uplift, erosion, and subsidence. The angular unconformities between these packages provide an opportunity to determine the kinematics of deformation at each stage of this history (fig. 2).

Continental margin strata and Antler foreland onlap sequence – C1

The Antler orogeny, commonly defined as Late Devonian obduction of ocean-margin strata onto the Paleozoic miogeocline, is thought to be the first collisional disruption of the western margin of North America. Nonetheless, it is difficult to ascertain what structural features formed as a result of this collision. This is because there are several overprinting events that are contractional and roughly coaxial, and there is a general lack of overlap strata that would constrain the age of structures. The Roberts Mountains thrust (separating allochthonous rocks from the miogeocline section, and often thought of as the "Antler thrust") can be shown to have several episodes of motion. Its age is constrained only as older than Permian based on dated overlap strata. The age of folding in the Roberts Mountains allochthon likewise is difficult to pin down; the oldest overlap strata are Permian rocks. The principal signal of the Antler orogeny is the foreland basin that resulted from loading by the allochthon. Sediments that filled this basin document its geometry and setting (Poole, 1974; Poole and Sandberg, 1977).

Middle Mississippian deformation and overlap strata – C2

In late Osagean or Meramecian time, the Antler foreland was deformed by a contractional event that also affected miogeoclinal rocks (Trexler and others, 2003). This deformation has been documented throughout the Piñon Range and south to the Diamond Mountains (*e.g.*, Silberling and others, 1997); the stratigraphic signal is ubiquitous throughout the Great Basin. In the Carlin area, this boundary is an angular unconformity with an overlap unit (Tonka Formation) that constrains the deformation to be pre-Chesterian. We will discuss this boundary in detail on the Ferdelford Canyon leg of the trip.

Pennsylvanian disruption – C3, C4, C5

Each of these boundaries is best expressed elsewhere in the region and will not be discussed in detail on this trip. However, at Carlin Canyon two of these boundaries are lithostratigraphic breaks, probably caused by deformation elsewhere; C3 is the Tonka-Moleen contact, and C4 is the Moleen-Tomera contact. The C5 contact was removed here by erosion on the C6 boundary.

Missourian deformation and overlap – C6

The C6 boundary is the centerpiece of the story at Carlin Canyon. All strata older than Missourian are dramatically deformed. The oldest overlap unit is the mid-late Pennsylvanian Strathearn Formation (lower member).

Early Permian regional event – P1

The P1 boundary at Carlin Canyon subtly truncates the lower member of the Strathearn Formation, cutting down to the east. Upper Strathearn Formation overlaps both lower Strathearn and deformed Pennsylvanian rocks. The characteristics of the lower and upper Strathearn here are so similar that mapping the boundary is very difficult except where deformation of the lower member is more pronounced. We initially recognized the boundary here based on biostratigraphy. The best expression of this event documented to date is near Beaver Peak in the Tuscarora Mountains, where lower Strathearn is caught up in thrusting; this deformation is depositionally overlapped by upper Strathearn (Theodore and others, 1998; Berger and others, 2001).

ROAD LOG—ELKO TO CARLIN

Mileage Cum.	Inc.	
0.0	0.0	Begin this leg of the trip in Elko at the intersection of Interstate 80 and Nevada State Route 225. Drive west along the Humboldt River valley on Interstate 80.
5.0	5.0	The view to the south is the mouth of the South Fork of the Humboldt River, where it flows north out of a deep canyon to enter the main Humboldt River valley. The deep canyon was cut (presumably) by Pleistocene outwash from Ruby Mountains glaciation.

HISTORICAL NOTE: The "Hastings Cutoff" used by some California-bound settlers followed the South Fork of the Humboldt River. It was supposed to be a shortcut to the main trail west. The Hastings Cutoff left the main trail in Utah and crossed the Great Salt Desert to rejoin the main trail here, saving miles but adding weeks to the trek. The ill-fated party of immigrants including the Donner family passed here in September of 1849, well behind schedule. They intended to cross the Sierra before early winter snows sealed the passes. They were already too late.

8.5-9.5	3.5-4.5	Grindstone Mountain is the ridge to the south (left) with the microwave tower on top. Here, the Mississippian-Pennsylvanian section is structurally duplicated. The structural break occurs at the topographic step one-third of the way up the north slope. The lower section is mostly Morrowan-Atokan Moleen and Tomera Formations. Above the step, the upper slope is Tonka Formation overlain (with an angular unconformity) by cyclothemic Morrowan-Atokan Ely Formation. Mapping by Smith and Ketner (1998) shows the lower, north block as being down-dropped along a north-dipping normal fault, but the fact that the two sections have very different lithostratigraphy argues against a simple normal fault interpretation. This problem has not been resolved.
12.5	3.0	The hoodoos on the right with horizontal bedding are mapped by Smith and Ketner (1978) as Eocene conglomerate. Behind (stratigraphically beneath) a buttress unconformity are

subvertical beds of the Moleen – Tomera Formations. Stratigraphic "tops" are toward the northwest, and the bedding is locally overturned. The southward continuation of this northwest-vergent overturned anticline-syncline pair can be seen along strike on the south side of the Humboldt River in the bluffs directly ahead to the west.

14.0 2.5 "The amphitheater" is on the right. This dramatic cliff of Pennsylvanian-Permian limestone will be the main subject of a Stop on the Carlin Canyon leg of the field trip.

15.0 1.0 Cross the Humboldt River and enter the highway tunnel. When you exit the tunnel, look to the right to see the C6 unconformity, pictured in many textbooks as a classical angular unconformity.

16.3 1.3 University of Nevada, Reno, Fire Science Academy is on the right. Continue west.

18.8 2.5 East Carlin exit. Leave the freeway here and follow Route 221 into Carlin. Alternatively, stay on the freeway to the Central Carlin exit. We will begin the Carlin Canyon segment here at the east Carlin exit. This ends the segment.

FERDELFORD CANYON

Mileage
Cum. Inc.

0.0 0.0 Begin this trip segment at the four-way Stop intersection just south of the main Carlin exit of Interstate 80. This intersection is in the center of Carlin, Nevada. Turn onto, or continue on, Route 221 west out of town. Note the very conservative speed limits in town.

1.4 1.4 Turn left at the Stop sign, onto state Route 278 south toward Eureka. Drive south on Route 278, following the Humboldt River and the route of the original transcontinental railroad toward Palisade.

HISTORICAL NOTE: Clarence King and the U.S. Geological Survey 40th Parallel Survey came through this country in 1868 (fig. 3), about the time that the transcontinental railroad was being built. King returned to the area in 1872 to inventory gold mines for the U.S.G.S., visiting, among others, the Bullion Mine just east of Piñon Peak. The infamous Diamond Rush of the early 1870s was just getting under way, and King soon played a role in exposing the hoax.

At this point you are more or less on the modern "Carlin Trend" of disseminated gold deposits. Most of the large mines operated by Newmont and Barrick are to the northwest in the Tuscarora Mountains. The active Rain Mine (Newmont) and the inactive Bullion Mine are to the southeast in the northern Piñon Range. According to Dr. Tommy Thompson, Director of the Center for Research in Economic Geology at the University of Nevada, Reno:

> *"The Carlin trend is the largest gold-producing district in the U.S., and in April 2002, passed the 50 million ounce production threshold. Due to this prominence Nevada ranks third, behind South Africa and Australia, in world-wide annual gold production. Gold occurs in arsenian pyrite and arsenian marcasite in deposits localized by shelf carbonates that have suffered decarbonatization and silicification. Structural controls are prominent in all deposits as well.*
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> *Research by the Ralph J. Roberts Center for Research in Economic Geology (CREG) has demonstrated that the gold deposits are Eocene in age (36–42 Ma), commonly localized in close proxim-*

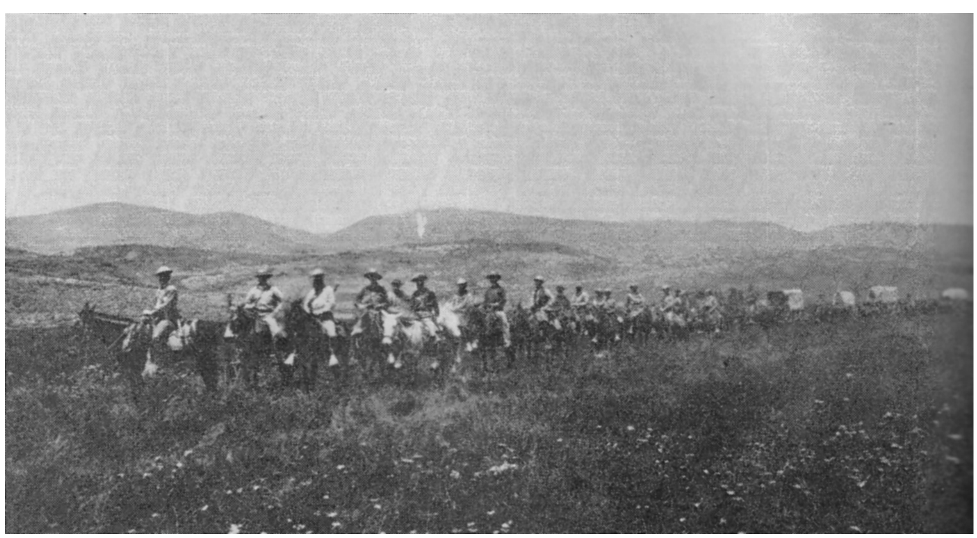

Figure 3. The 40th Parallel (King) Survey crosses Nevada in 1868. Photo by T.H. O'Sullivan.

ity to igneous rocks of the same age. Stable isotope analyses by CREG researchers have demonstrated that the deeper Carlin-type gold deposits have a significant component of magmatic waters related to their formation."

Mileage Cum.	Inc.	
2.6	1.2	Cross the railroad track and the Humboldt River. Volcanic flows forming the canyon walls are the Miocene Palisade Canyon Rhyolite.
10.4	7.8	Intersection with a road that goes right to the townsite of Palisade. Route 278 departs from the river and the railroad here to follow the tributary drainage of Pine Creek and Pine Valley southward.

HISTORICAL NOTE: Palisade Canyon of the Humboldt River proved to be a relatively minor barrier to construction of the transcontinental railroad (fig. 4), allowing the railroad to maintain grade from the Carson Desert all the way up the Humboldt River to its headwaters. From Elko, the original route runs northeast to Wells, and then north past the Goose Creek Mountains to Promontory Utah, where the Central Pacific and Union Pacific met in 1868.

The bluffs through which Pine Creek flows are in the Miocene Humboldt Formation. Piñon Peak, the sharp tree-covered peak on the southern skyline, is underlain by Devonian Devils Gate and Nevada Formations. These limestones and dolomites are the upper part of the North American miogeocline and are in the footwall to all thrusting in the area.

15.7	5.3	Turn left to drive up Ferdelford Canyon on a graded dirt road. This turn is obscure, but can be recognized because it is opposite the Brown Ranch, on the right side of the highway. As you drive up this canyon you are going down section. The steep sage-covered hillsides are Miocene Humboldt Formation, which rarely crops out.
18.5	2.8	Cross the cattle guard at the "Tomera Ranches" sign. Conglomerate outcrops in the

Figure 4. First construction train steams through Palisade Canyon in 1868. Photo by Alfred Hart.

bluffs ahead are the late Mississippian Tonka Formation. Fossil beds just uphill on the left date this Tonka as Chesterian. Bedding in the Tonka here dips gently north.

19.3 0.8 The cottonwoods on the right mark the site of the Webb Ranch, after which Webb Creek and the Webb Formation were named. Original ranch buildings stood on this site until the late 1980s.

19.7 0.5 Follow the graded road where it turns south (right), crosses Ferdelford Creek and climbs a side canyon up Webb Creek.

20.5 0.8 The lower Mississippian Melandco Formation crops out in road cuts here. We will Stop to look at it on the way down the hill. It is shale and chert-litharenite turbidite beds with some heterolithic conglomerate. The Devonian Webb Formation is poorly exposed in fault-bounded blocks a little further up the canyon.

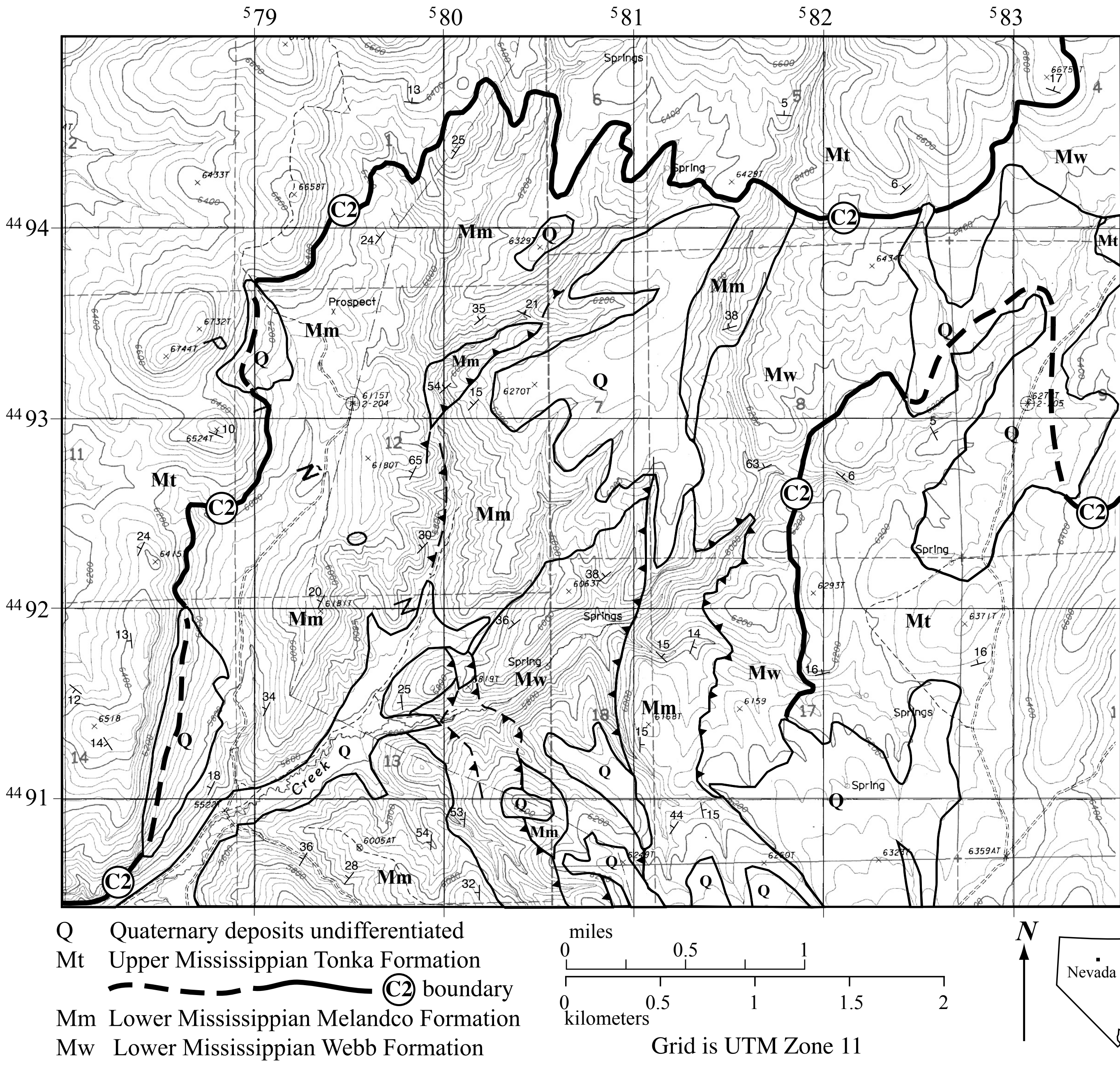

Figure 5. Map of part of the Raven's Nest quadrangle by R. Tosdal, as published in Trexler and others (2003).

21.0 0.5 Devonian Woodruff Formation crops out in the road cut on the right. We will Stop and look at these road cuts on the way down the hill.

21.6 0.6 The road climbs up and reaches an old pediment at a maintained fence line. Turn acutely north and proceed in vehicle or on foot (depending on road conditions, there is a year-round seep here) north on the faint jeep track that will take you about 0.5 miles to the end of the ridge. This short detour is not counted in the road log mileage.

Stop 1. View point on the ridge, overlooking the canyon to the north. The view to the north is the map area in figure 5. The rocks along the skyline to the north are late Mississippian (Chesterian) Tonka Formation. They are gently folded, but generally flat-lying. The base of the Tonka is the C2 boundary, regionally constrained to be upper Meramecian to lowest Chesterian. The rocks beneath the C2 boundary are Late Devonian Woodruff, earliest Mississppian Webb, and Mississippian Melandco Formations. These are deformed and repeated by east-vergent folds and east-directed thrust faults; this deformation is truncated by the C2 unconformity (fig. 6). For a more complete discussion of the mid-Mississippian deformation event, see Silberling and others (1997) and Trexler and others (2003).

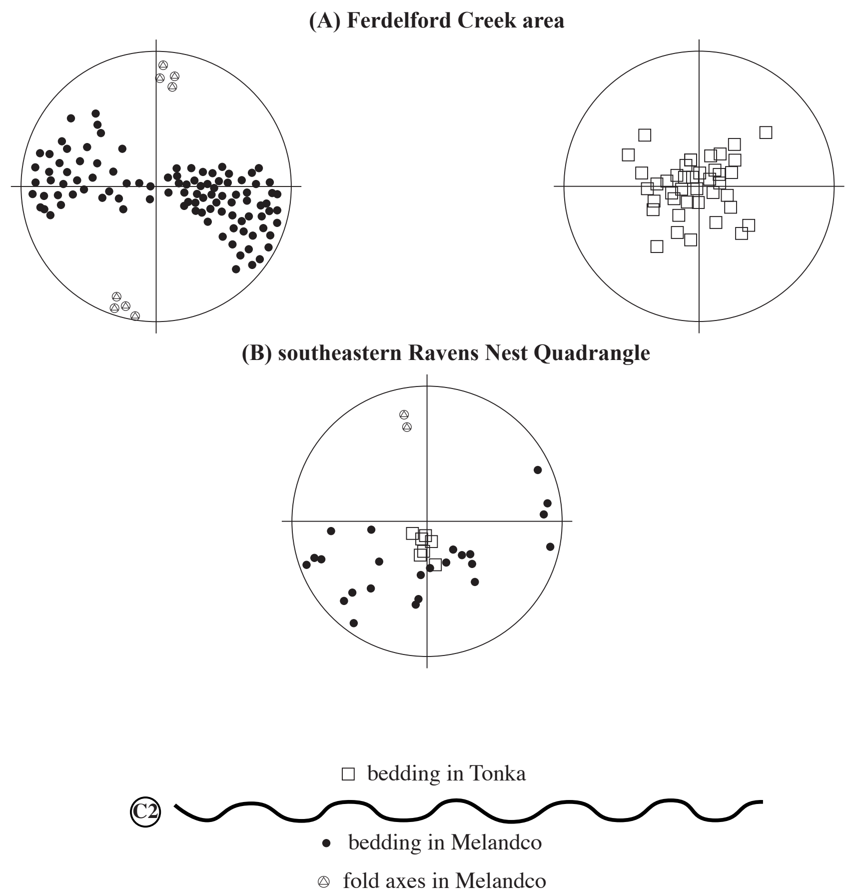

Figure 6. Stereogram of fold axes and poles to bedding above and below the C2 unconformity (Tonka and Melandco Formations, respectively) in the southeast part of the Raven's Nest 7.5 minute quadrangle. The Melandco Formation is folded around north-south axes and the Tonka Formation is not. This deformation therefore occurred in mid-Mississippian time; see text for discussion of age control. Data are from mapping by Tosdal (as published in Trexler and others, 2003).

ECONOMIC GEOLOGY NOTE (Dr. Tommy Thompson): The Rain Mine is visible to the northeast. The Rain Mine is localized along the N. 40–50° W.-striking, 80–45° SW.-dipping, dextral Rain fault. The orebodies are hosted in hydrothermal breccias localized within the hanging wall of the Rain fault, and within the Mississippian Webb Formation immediately overlying the contact with the Devonian Devils Gate Limestone. The orebodies were mined in open pit (1.17 Moz gold) and in underground stopes (265 Koz gold). The open pit concentrations were 1.8 g/t Au while the underground grades average 7.7 g/t Au.

STRATIGRAPHIC NOTE: Several earlier maps have shown the fine-grained rocks of the Webb and Melandco here as "Chainman Shale" and the coarser Melandco as "Diamond Peak Formation". We have abandoned both "Chainman" and "Diamond Peak" in this area (but not entirely, see Trexler and others, 2003) because the names are ambiguous—they have been applied to different age rocks in different places. In some areas these units, as originally named, contain one or more tectonostratigraphic boundaries. As we will see on this trip, formation designation based on gross lithostratigraphy obscures stratigraphic and structural relationships. Previous workers have recognized the significance of deformation here (Jansma and Speed, 1990; Silberling and others, 1997; Tosdal, unpublished mapping and in Trexler and others, 2003).

Another problem in this area concerns the black shale and argillite underlying the Melandco Formation. Devonian Woodruff and Mississippian Webb are particularly difficult to tell apart; many workers have relied on scanty fossil data to differentiate these two on the basis of age. Although both are mapped in the area (Smith and Ketner, 1978), work by geologists in the Rain Mine pit (see economic geology note above) documents Webb Formation conformably on Devonian Devil's Gate Formation. These problems are not resolved.

Return south to the graded dirt road. Turn right and return down the canyon. Continue cumulative mileage as you drive down the canyon.

Mileage		
Cum.	Inc.	
22.2	0.6	Park for Stop 2.

Stop 2. Look at the Woodruff Formation in outcrop. The Woodruff Formation is black argillite and siltstone, rarely exposed. Age control is based on radiolaria preserved in ellipsoidal phosphatic nodules. These radiolaria have been dated at this locality as Famennian (latest Devonian) (P. Noble, written communication, 2003).

The Woodruff and Webb Formations are considered by many workers to be the initial foredeep mudrocks deposited in the Antler foreland basin, recording the initiation of foreland basin subsidence and, therefore, dating the Antler Orogeny. The C1 boundary lies beneath the Webb (or Woodruff) and above the rocks of the carbonate miogeocline. As stated above in the note on the Rain Mine, there the Webb lies conformably on the Devonian Devil's Gate Limestone, tying it depositionally to the carbonate miogeocline.

Continue back down the canyon the way you came up. Cumulative mileage continues.

Mileage		
Cum.	Inc.	
22.8	0.6	Park for Stop 3.

Stop 3. Look at the Melandco Formation in outcrop. The Melandco is made up of heterolithic conglomerate, litharenite, and mudrock. Here, the section is mostly mudrock with 1- to 5-m intervals of conglomerate that are matrix rich to matrix supported. Clast types in the conglomerates include chert, litharenite, quartzite, limestone, and rare volcanic rocks. (This is in contrast to the overlying Tonka conglomerates, which contain none of the less resistant clast types.) The Melandco contains graded beds generally less than 1-m thick. These beds typically preserve characteristics of density-modified flow or turbidity current deposits. Scours and bases of channels indicate east and southeast flow directions. The Melandco is not fossiliferous here and rarely is elsewhere, but regionally it is constrained to Osage to early Meramec in age. These beds have been interpreted as Antler foreland submarine fan deposits, with the sediment source being the Antler highland to the west (Poole, 1974; many others).

STRATIGRAPHIC NOTE: We have chosen to call these rocks "Melandco", and not "Chainman", as they have often been mapped. The term "Chainman" is not appropriate, because the type Chainman, in the Ely area, is significantly younger in age (Chesterian), and lies above the regional C2 boundary. The term "Melandco" in its type area was originally applied to foreland basin submarine fan rocks of this age east of Elko in the Snake Mountains, and thus is appropriate here both in age and in lithology. This unit also could legitimately be called "Dale Canyon Formation" (Silberling and others, 1997), the equivalent unit in age and tectonic significance to the south in the Eureka area.

Continue to the main canyon bottom, and turn left to go back down Ferdelford Creek.

Mileage		
Cum.	Inc.	
23.8	1.0	A large float block of Tonka Formation conglomerate sits on the right side of the road. We will Stop in Carlin Canyon later today to look at the Tonka in detail.

Rejoin Route 278 and retrace route northward to Carlin. This ends the segment.

CARLIN CANYON

Mileage		
Cum.	Inc.	
0.0	0.0	Interstate 80 freeway onramp at East Carlin.

ROUTE NOTE: Because we must use I-80 to travel between stops in this segment, we will need to do some doubling back in order to visit the next few stops in a logical—chronological—order. We do not advocate stopping on the Interstate to look at road-cut outcrops. It is dangerous and probably illegal.

Drive east on the frontage road on the south side of the interstate. Follow Bureau of Land Management (BLM) signs to Carlin Canyon.

As we drive east from Carlin toward Carlin Canyon, the Ordovician Vinini, upper Devonian Woodruff, and lower Mississippian Webb Formations underlie the monotonous low-relief slopes to the north and south. The steep slopes at the entrance to the canyon are held up by Mississippian conglomerates. The Webb is mapped in fault contact with the lower Mississippian Melandco Formation. This is a steep fault that is apparently reverse on the north side of the highway; on the south side, map relations indicate Webb is thrust over Mississippian rocks, but the timing of thrusting is not known.

Mileage		
Cum.	Inc.	
1.8	1.8	The bridge across the highway to the left goes

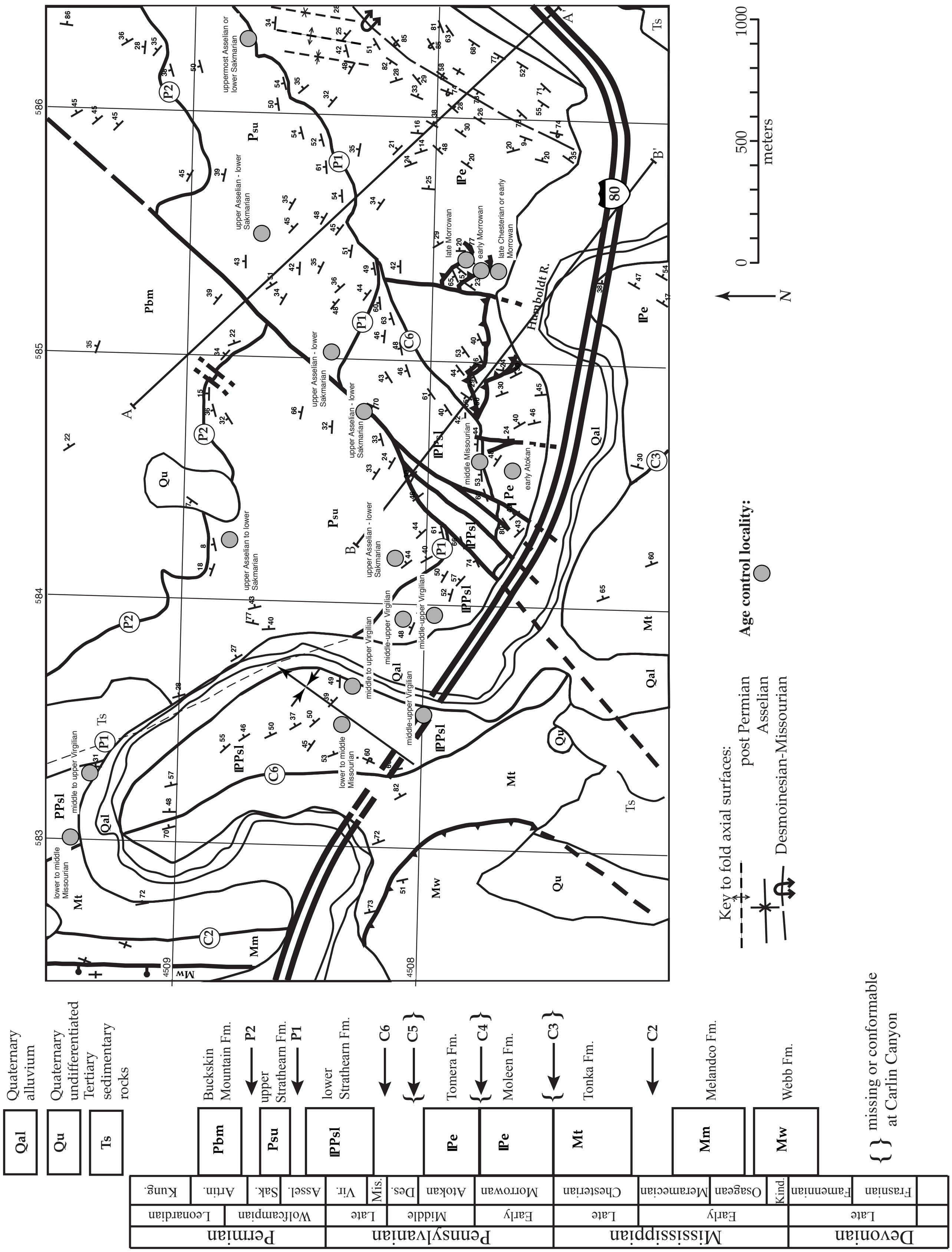

Figure 7. Map and stratigraphy of the Carlin Canyon area, as published in Trexler and others (2004).

to the University of Nevada, Reno, Fire Science Academy; continue straight.

The wetlands to the right are part of Newmont Mining's wetland mitigation project. As we approach the tunnel portals in the canyon, we are on the map in figure 7.

3.4 1.6 **Stop 4.** The view to the north, across the freeway, shows the C2 unconformity (fig. 8). The subvertical beds on the right are the lowest Tonka Formation, which is in angular unconformity over the Melandco Formation to the left. We will be able to walk back to examine this contact from the next stop.

3.6 0.2 Cross beneath I-80 to the north side of the freeway.

3.9 0.3 **Stop 5.** BLM wayside Stop (view of the C6 unconformity a short distance up-river to the north); park on the left side of the road in the gravel lot. We will look at the C2 unconformity at the west end of Carlin Canyon, and at the Tonka Formation. Begin by walking up the abandoned freeway ramp to the west.

The Melandco Formation here is predominantly heterolithic conglomerate and coarse litharenite, with rubble intervals that are mudrock and argillite. Clast counts document a number of different clast types, including friable quartzarenite, which might have a source in the Harmony Formation. The conglomerates generally lack recognizable fabric other than crude bedding-plane-parallel long-axis orientation of clasts. These strata are interpreted as density-modified flow and high-density turbidity current deposits and are thought to be primary Antler foreland basin fill. Paleocurrent indicators (elsewhere) as well as abundant radiolarian chert clasts document a western source in the Antler orogenic highlands.

The C2 boundary is marked by a change in attitude from vertical beds of the Melandco to steeply east-dipping beds of the Tonka (fig. 8). This angular unconformity can be mapped south throughout the Piñon Range, the Diamond Mountains, and the northern Fish Creek Mountains, a distance of over 150 km.

The Tonka Formation comprises clean chert-quartzite conglomerate and litharenite, interbedded with calcareous silt-

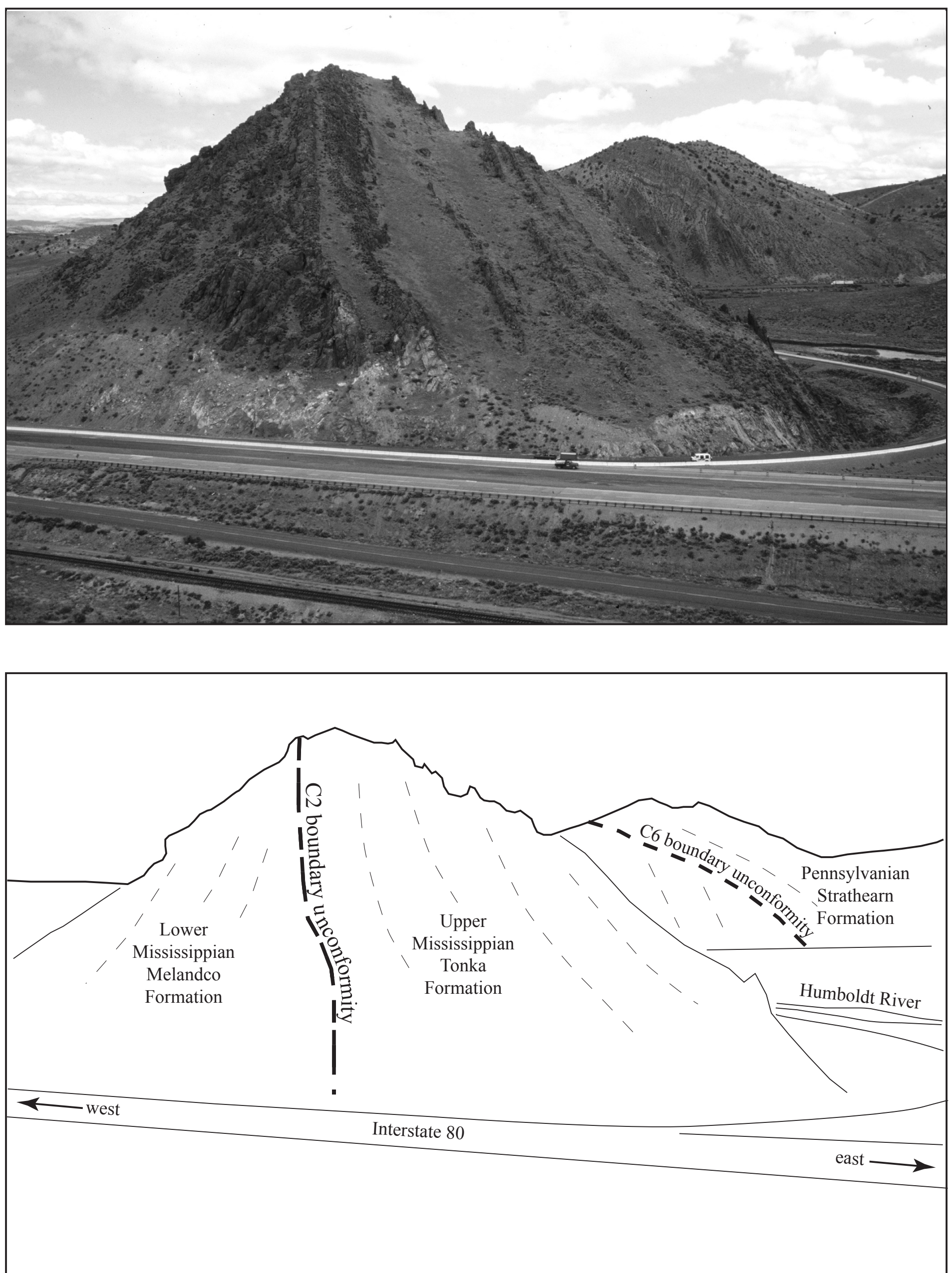

Figure 8. West end of Carlin Canyon, looking north. The C2 boundary is the angular unconformity in the foreground, and the C6 boundary can be seen in the background to the right. See text for discussion.

stone and sandy limestone. The conglomerate and litharenite preserve channel geometries, trough cross-bedding, bar foresets, and other features consistent with fluvial processes. The siltstones and carbonates are sandy and fossiliferous, lenticular bodies, interpreted as overbank deposits and lagoonal facies. The overall setting for the Tonka is interpreted as marginal-marine deltaic. Fossils in the Tonka range through the Chesterian in age. The pronounced shift in depositional environment, as well as the angular unconformity, emphasize the importance of the C2 boundary.

This Stop gives an excellent view of the C6 boundary unconformity a short distance to the north. Subvertical beds of Tonka Formation are truncated by steeply dipping beds of the lower (Missourian) member of the Strathearn Formation. Note that the geometric relationships are the same as the C2 boundary unconformity, suggesting progressive, and probably coaxial, deformation. Considerable section is missing here that is not missing at the east end of the canyon: upper Tonka, Moleen and Tomera Formations have all been removed by erosion under the C6 unconformity.

Mileage		
Cum.	Inc.	
4.3	0.4	**Stop 6.** The gray beds are the base of Strathearn Formation in angular unconformity (C6) over reddish Tonka conglomerate and litharenite.

The C6 unconformity is hidden at road level, but is exposed in outcrops on the steep hillside to the north. There, the lowest Strathearn is a red-stained paleosol containing fragments of the underlying Tonka. Relief on the Tonka is limited at map scale here, but at outcrop scale the surface is irregular. These characteristics indicate that the Tonka – Strathearn contact here is an uncomformity. Note that although this contact was initially described as an unconformity (Dott, 1955), some subsequent workers have interpreted it to be a fault (*e.g.*, Jansma and Speed, 1990). We have examined the contact closely and have not found evidence for significant faulting along it. Locally, there has been a small amount of slip, probably as flexural slip during later folding.

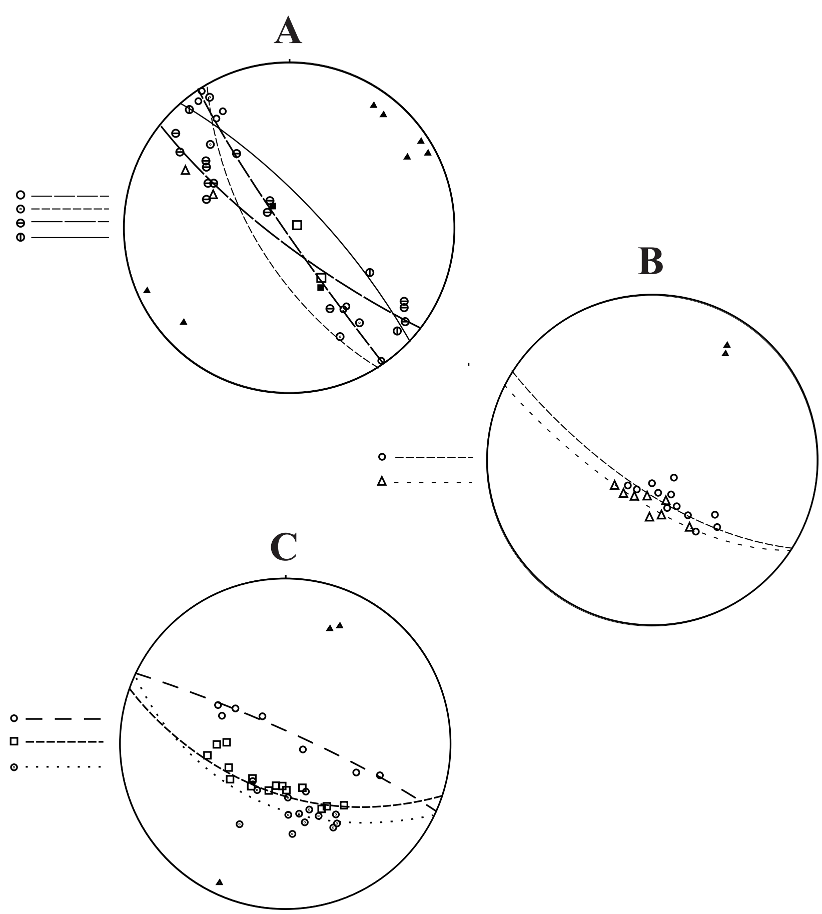

Figure 9. Stereograms of the three different fold sets in the Carlin Canyon map area. All are lower hemisphere, equal-area plots, with poles to bedding shown as circles, squares, or open triangles. Different symbols represent individual mesoscopic or macroscopic folds. Fold axes for individual folds are shown as filled triangles.
(A) Pennsylvanian (C6) deformation, characterized by asymmetric to overturned folding, and northwest-directed thrust faulting. Stereogram shows poles to bedding in macroscopic, mesoscopic and hanging-wall folds, with individual fold axes plotted. Fold axes most commonly trend east-northeast (050°-065°). Note: The subsequent deformation has not been rotated out for most of these folds, because the overlying Strathearn Formation is not preserved. However, the three folds where subsequent tilt has been removed do not differ systematically from the other folds on this stereogram, indicating that subsequent rotation is not significant here. (Fold axis orientations, presented as plunge/trend: 11/037, 08/039, 04/056, 04/063, 18/059, 02/246, 12/228.)
(B) Lower Permian (P1) deformation, characterized by open, upright folds. The tilt of the overlying upper Strathearn has been removed, and the P1 fold axes plunge gently toward 030°-032°. (Fold axis orientations, presented as plunge/trend: 16/032, 13/030.)
(C) Post-Permian deformation, characterized by open, upright folds. The fold axes plunge gently toward 020°-026°. (Fold axis orientations, presented as plunge/trend: 21/026, 25/020, 05/205.)

Continue upriver on the old highway. Cliffs on the left (east) are the upper (lower Permian) member of the Strathearn. Bedding strike in these rocks is parallel to the highway (see fig. 7).

Mileage Cum.	Inc.	
5.3	1.0	**Stop 7.** Lower Strathearn, across the river to the right, is folded below the unconformity with the upper Strathearn; the unconformity is under the river here. Bedding in the lower Strathearn is folded into a broad syncline and strikes directly down the hill toward us, and upper Strathearn behind us is unaffected. This is the P1 unconformity. See figure 9 for structural data from this area. Return toward East Carlin via the old highway (back the way you came).
10.6	5.3	East Carlin freeway ramps. Turn right, and immediately right again to get on Interstate 80 east toward Elko. Continue cumulative mileage.
14.1	3.5	Enter the freeway tunnel eastbound.
15.1	1.0	Tonka railroad siding is on the right; this is the type section of the Tonka Formation (Dott, 1955). This was an unfortunate choice of type locality, because the section is duplicated in at least one place by thrusting.
16.2	1.1	Just beyond the second bridge over the river, pull off the freeway to the right into the small dirt pullout where a graded dirt road goes through a gate to follow the railroad (the gate may be locked). Pull well off this busy, high-speed highway. Walk through or climb over the gate, and climb up to one of several vantage points looking north across the railroad, river, and Interstate 80 at the south-facing cliff-face, a locality we refer to as "the amphitheater."

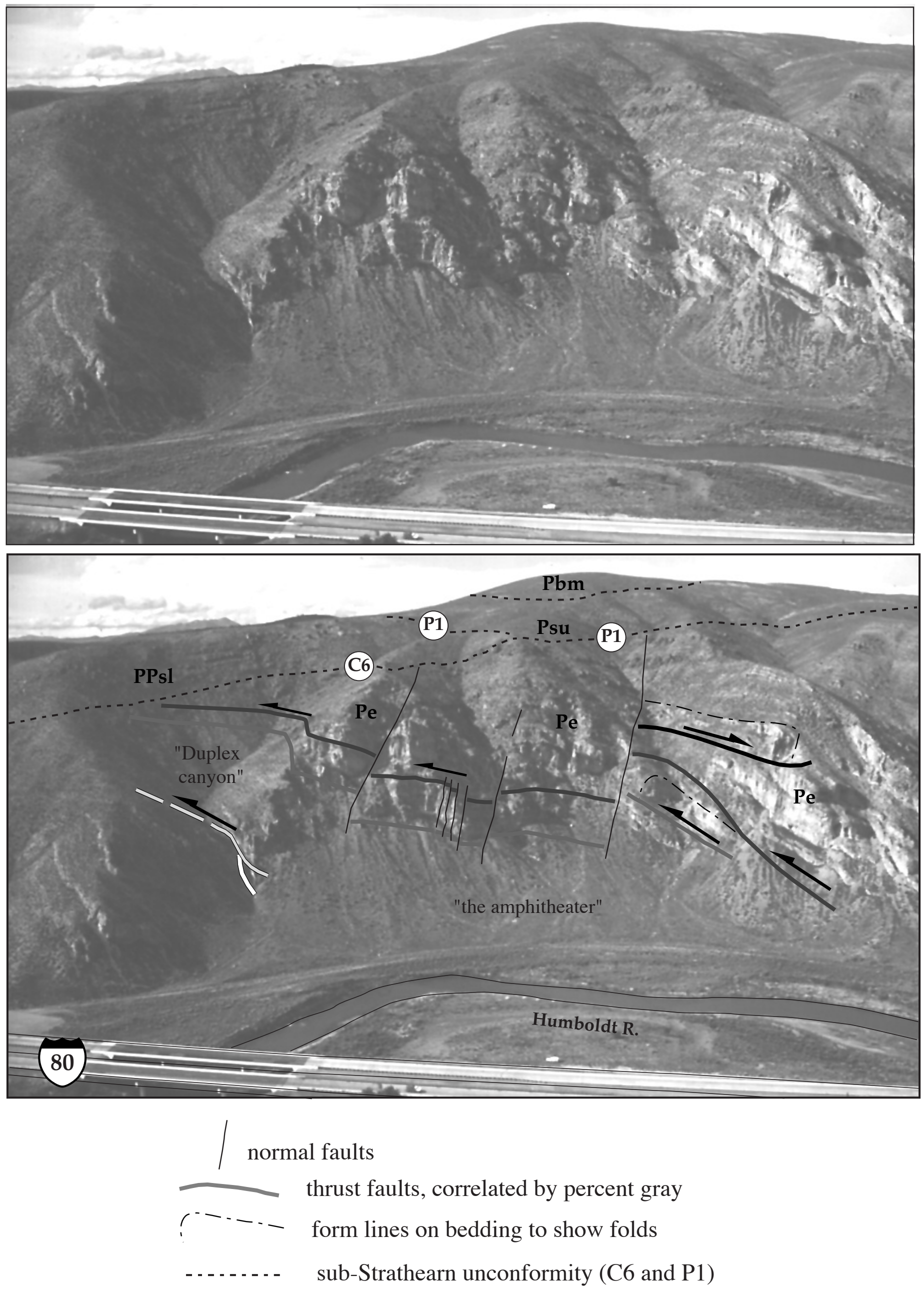

Figure 10. Annotated photograph of "the amphitheater": a view to the north at the south-facing wall in the eastern part of Carlin Canyon. A discussion of the structure displayed here is in the text.

Stop 8. Strata of "the amphitheater" display the structures developed during Missourian thrusting and folding here at Carlin Canyon (fig. 10). In order to understand this structure, we have mapped the entire cliff face using a total station posi-

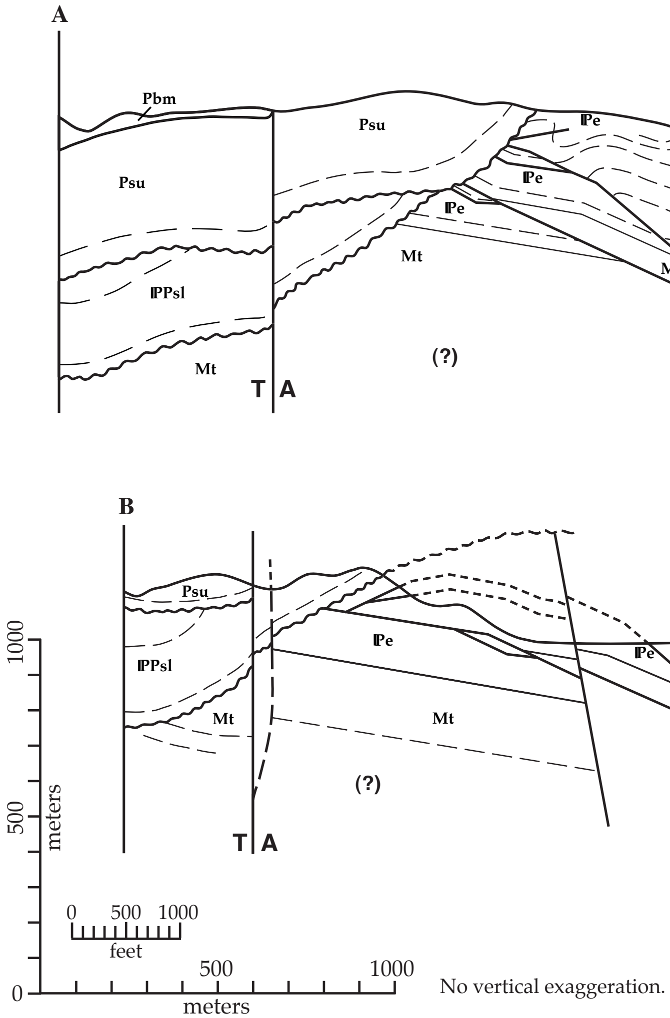

Figure 11. Cross sections through the Carlin map area. See map (fig. 7) for locations.

tioned at this vantage point. This detailed mapping, combined with fusulinid biostratigraphy, enabled us to work out the complex structure. The photo for figure 10 was taken at the top of the hill directly behind you to the south. See figure 11 for our interpretation of this structure in cross-section.

Units in the cliff are the Moleen and Tomera Formations and are Morrowan through Atokan in age. These strata are thrust faulted and folded, and eroded along an unconformity (P1) that is near the skyline as viewed from here. Overlying the unconformity here is the upper Strathearn; it is the highest carbonate one can see from this vantage point. The Permian Buckskin Mountain Formation overlies the Strathearn and caps the mountain to the north. Note that the lower member of the Strathearn (which underlies the upper Strathearn at Stop 7, and overlies the Tonka along the C6 unconformity at Stop 6) is not present here. It has been removed by erosion along the P1 boundary unconformity prior to the deposition of the upper Strathearn.

The Missourian deformation at Carlin Canyon is dominated by northwest-vergent folding and several northwest-directed thrust faults. In the cliff face, you can see two minor thrusts that step up-section in the footwall toward the northwest (fig. 10). These faults have northwest-vergent hanging wall anticlines with amplitudes of tens of meters. In the canyon we call Duplex Canyon at the west end of "the amphitheater" several more thrusts are exposed. These, too, are northwest directed, as shown by footwall truncations (upsection toward the northwest) and ramp anticlines in the hanging walls. A southeast-vergent thrust with hanging-wall anticline can be seen high in the wall at the east end of the amphitheater. The fold is coaxial with the northwest-vergent folds, so this structure appears to be a local back thrust, accommodating the same northwest-southeast shortening as the northwest-vergent fold-thrust system. A marker horizon ("Chaetetes horizon" of Dott, 1955) crops out at the base of the exposure at the west end of "the amphitheater", and high on the slope out of sight to the east of the amphitheater. The stratigraphic separation across these thrusts is, therefore, several hundred meters. A large northwest-vergent overturned anticline-syncline pair just east of the amphitheater accommodates more northwest-southeast shortening; the subvertical bedding (described at Mile 12.5 Elko to Carlin road log) forms the common limb of this fold pair.

Although all three folding events recorded at Carlin Canyon have northeast-plunging axes, they can be distinguished based on details of fold style and geometry (Trexler and others, 2004). The Missourian, sub-C6 deformation, is characterized by northwest-verging overturned folds and thrusts described in the preceding paragraph. Fold axes appear to trend about 060°. Sub-P1 (earliest Permian) folds (*e.g.*, at Stop 7) are open and upright with axes plunging gently toward 030°-035°. Post-Permian deformation consists of open 020°- to 025°-trending folds in the few exposures where we have seen it. Work in progress by UNR graduate student Tristan Ashcroft will further define this deformation.

Carefully get back on the freeway and continue east on Interstate 80.

Mileage Cum.	Inc.	
18.9	2.7	To the right, on a point bar of the Humboldt River adjacent to the black railroad bridge, you may see a long-lived example of local folk art. Many generations of lawn flamingoes have appeared in various configurations here for at least 15 years.
22.1	3.2	Exit at Hunter (exit 292). Maggie Creek Ranch is on the right. If you wish to return to west-bound I-80, cross over the freeway and get back on. This ends the segment.

Part 2: Thrust Faults, Unconformities, and Reactivation of the Roberts Mountain Allochthon

During this segment of the trip, we (1) continue the themes of upper Paleozoic tectonism and widespread unconformities raised during Part 1, (2) highlight the depositional environment for these Antler foreland basin (C1–C2) strata (Stop 10), (3) examine deformed C1–C2 strata overlapped unconformably by post-P4 units (Stop 11), and (4) see pre-P4 structural reactivation of the Roberts Mountains allochthon (Stop 13). At the last stop, we also will have a chance to discuss the nature of the Antler orogeny and the mechanics of deformation of bedded chert.

The Northern Adobe Range is structurally dominated by the Adobe syncline (Ketner and Ross, 1990). The syncline is cored by Triassic rocks, and is, therefore, a Mesozoic-Cenozoic structure. We will look at Mississippian and Permian strata on the eastern limb, traverse across the axis of the syncline, and see Late Devonian, Mississippian and Permian strata on the western limb. If road conditions permit, we will continue west/northwest along the road and exit onto Nevada State Highway 225 and return to Boise; otherwise, we will return to Elko and then to Boise.

Figure 12. Stop 11, basal conglomerate of Permian (Guadalupian) age overlying Early Mississippian Melandco Formation. Note fragments of Melandco in carbonate matrix (inset).

ROAD LOG—COAL MINE CANYON

Please note that the mileages for this portion of the road log are approximate, because we had to estimate them from aerial photographs. There should be no cumulative error.

Mileage Cum.	Inc.	
0.0	0.0	Begin this part of the trip at the East Elko Interchange of Interstate 80. Drive east on I-80 along the Humboldt River valley.
11.2	11.2	Turn off I-80 at the Ryndon exit (second exit from the start). Turn north and go under the interstate, bear west on the north side of the Interstate, then turn north on the well-graded gravel road. Don't worry about getting lost in this small residential development, just head north and you will be on the right road.
19.7	8.5	Intersection of the Coal Mine Canyon road and a dude ranch driveway; the dude ranch itself is approximately 1 mi north of this intersection. Turn left (west) on the unmarked Coal Mine Canyon road.
22.9	3.2	Make a 90° right turn (north) into Coal Mine Canyon; there are several houses near the road.
25.5	2.5	**Stop 9.** Here, we will discuss the Mississippian conglomerates that are near prominent white cliffs (Eocene Elko Formation), where the road begins to enter the narrower part of the canyon. Stop where there is a good view of the conglomerates (mapped as "Pennsylvanian-Mississippian Diamond Peak Formation") that cap the Adobe Range.

The "Diamond Peak" nomenclature is difficult to use in this part of the Great Basin because Mississippian conglomerates here can be either part of the Antler foreland basin (C1 to C2) or Antler successor basin (C2 to C3) sections. The former is part of the Melandco, the latter, part of the Tonka (as originally defined by Dott, 1955). The sharp contact between the underlying fine-grained strata and these conglomerates reflects either an abrupt shift from distal mudrocks to submarine channel facies of the Melandco, or the C2 unconformity with Tonka overlapping the finer-grained Melandco. The lack of age control and the massive nature of these conglomerates hamper the interpretation. These are the same conglomerates viewed at the informal Stop on Nevada State Highway 225 approximately 3 mi west of Elko.

Mileage Cum.	Inc.	
26.8	1.3	**Stop 10.** This is the Melandco Formation, characterized by sandstone horizons and polymict debris flows within shale and siltstone. The purpose of this Stop is to demonstrate the basinal facies of the Melandco, the true Antler foreland basin (C1 to C2, our terminology), for contrast with the deposits of the Antler successor basin (C2 to C3), seen yesterday. Recall that the Melandco (C1 to C2) units in Carlin Canyon were inner submarine-fan conglomerate and litharenite, which differs from this mudrock-dominated submarine fan section. The fine-grained sections are not exposed, making accurate fan models impossible.
27.3	0.5	**Stop 11.** The structure of the northern Adobe Range is dominated by the Adobe Range syncline, in the core of which lie Triassic strata. It is, therefore, clearly a Mesozoic structure. Stop 3 is on the southeast limb of the syncline.

Here, the Middle Permian (P4-P5/TR1) unconformably overlies deformed Melandco. We are still in Melandco along the road, but the ridge to the north-northwest is capped by Permian siliciclastic and mixed siliciclastic-carbonate units. As initially mapped (Ketner and Ross, 1990), the contact between the two is interpreted to be a thrust fault. However, we now know that it is an unconformity, and that the base of the Permian is a conglomerate including clasts from the underlying Melandco (fig. 12). As you walk up the hill, note the polydeformed nature of the Melandco below the contact with the Permian.

The unconformable nature of this Mississippian-Permian contact brings into question many of the other contacts in this area that have been mapped as low-angle faults. For example, the Mississippian-Permian contact on the northwest limb of the Adobe Range syncline also has been mapped as a thrust fault (Ketner and Ross, 1990). However, we have remapped a small portion of the area (near the head of Coal Canyon) and found similar relationships to those in Carlin Canyon, although the age of deformation is not as tightly constrained; interbedded black chert, argillite and siltstone of the Roberts Mountains allochthon (Ordovician Vinini Formation and Silurian Slaven Chert, Ketner and Ross, 1990) are tightly folded, with axes uniformly trending northeast. These are in thrust contact over homoclinal black mudstone that has been designated Mississippian "Chainman Shale" (we would call it Melandco) by Ketner and Ross (1990). Both the thrust contact and the tight folding are overlain by a Permian mixed carbonate/siliciclastic unit along what we interpret to be a depositional contact. The precise ages of these units within the Mississippian has not been determined; the Permian has yielded a Guadalupian brachiopod. The age of the thrusting here can, therefore, be dated only as post-"Mississippian" and pre-Guadalupian (Middle Permian). (Note: Although we don't know the age of the "Chainman" within the Mississippian, this siliciclastic sediment was deposited in the Antler foreland basin and was derived from the Antler allochthon. These rocks subsequently have been faulted against the Antler allochthon along a pre-Middle Permian fault.)

Our map of this area differs from the published map in that the Permian is everywhere in depositional contact on the underlying rocks and, therefore, overlaps the post-Melandco thrust fault. Our interpretation is based on the lack of penetrative deformation near the contact and on the consistent gentle dips in the basal Permian where it overlies both upper and lower thrust plates. This Late Paleozoic thrust, unconformity and overlying Permian section are tightly folded by Mesozoic deformation elsewhere in this area.

The deformation within the Melando could be associated with any one, or several, of the C2 through P4 events. However, it seems likely that this pre-Middle Permian deformation may correlate with that seen in Carlin Canyon. Although we have no direct data to support this interpretation at this time, the C6 and/or C5 deformation displayed at Carlin Canyon is the most intense post-Mississippian/pre-Middle Permian deformation yet documented in Nevada. It is thus the most viable candidate for the similar-age, relatively intense deformation here in the northern Adobe Range.

Mileage Cum.	Inc.	
28.0	0.7	**Stop 12.** This is the Triassic overlap; the fossil hunters in the group may find Triassic ammonoids here. We have no experience with this Triassic unit, and therefore quote directly from the map unit description of Ketner and Ross (1990):

> *"Shale and limestone (Lower Triassic) – A slope and basin deposit consisting of olive-drab shale, thin-bedded limestone with graded beds and sole marks, slump deposits, and bouldery olistostromes derived from the Gerster Formation. (The Gerster is an autochthonous Permian shelf limestone unit of eastern Nevada and western Utah.) Thickness estimated to be more than 2000 ft (610 m). The Triassic unit contains many dioritic sills a few meters thick and traceable for as far as 1.5 mi (2 km) parallel to*

bedding. Some of the sills contain smoothly rounded boulders of quartzite similar to the Eureka Quartzite, and of marble. Formation was dated by ammonoids and conodonts."

Ketner and Ross (1990) map the basal contact of these Triassic rocks as a low-angle fault rather than as an unconformity, because (1) they map tectonic slices of older Paleozoic units along the contact between the Permian and the Triassic, and (2) there appears to be an abrupt change in depositional setting between the Permian units—which locally contain evaporites and which they interpret to be shallow-water deposits—and the fine-grained, deep-water turbidites of the Triassic.

Alternatively, since we interpret many of the other "low-angle fault" contacts in this region to be unconformities, the Permian-Triassic contact here also may be an unconformity. This would simplify the post-Triassic deformation in this area but would not change the basic interpretation—that there was large-scale Mesozoic folding and thrust faulting. In addition, it would enlarge the geographic extent of yet another Late Paleozoic unconformity in north-central Nevada.

Mileage		
Cum.	Inc.	
30.0	2.0	**Stop 13.** There are several items of interest at this stop. The spectacular outcrops across the small gully are chevron-folded Late Devonian and Early Mississippian bedded chert. These deformed strata comprise a mappable, tectonostratigraphic unit (MDw) that lies structurally on top of younger Mississippian Melandco. This bedded chert succession is usually considered to be part of the Roberts Mountains allochthon, but it could also be part of the Rodeo Creek Formation or equivalent parautochthonous units of the outer continental shelf. These are well represented west of here, along the Carlin trend.

The nature of the folds within MDw suggests deformation occurred not long after deposition—it could correlate with the classic Antler orogeny, or other Mississippian or Early Pennsylvanian event(s); the nature of the deformation and possible interpretations will be discussed on the outcrop.

LOGISTICAL NOTE: Depending on recent weather conditions, we may have to turn around and retrace the route to Elko. There is a creek crossing 6.4 mi ahead that a van cannot cross if the creek has moderate-flow levels.

Mileage		
Cum.	Inc.	
35.9	5.9	Sharp left (west) turn toward creek.
36.4	0.5	Creek crossing.
36.9	0.5	Sharp (almost 90 degree) turn to the west.
37.7	0.8	90 degree turn to the south.
38.4	0.7	Nevada State Highway 225 (highway from Boise and Mountain Home to Elko).

This is the end of this segment.

Follow Highway 225 north through Mountain Home to Interstate 84, east on I-84 to Boise; approximately 185 mi total travel from where you enter Highway 225 to Boise (total approximately 220 mi from Boise to Elko). Note: Highway 225 turns into Idaho State Highway 51.

Acknowledgments

Many colleagues and students, over many years, have contributed to our understanding of the area traversed by this field trip. Bob Dott's seminal work in the area (1955) put us on the right track, and continues to be a reference bible. Geologic insights and age control have been provided by Norm Silberling, Scott Ritter, Bruce Wardlaw, John Groves, Tamra Schiappa, Paula Noble, CJ Northrup, Jennifer Titcze, Dustin Sweet, Ted Theodore, and Keith Ketner. Land access has been kindly provided by the Maggie Creek Ranch.

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